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Driver behaviour at roadworks

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Abstract

There is an incompatibility between how transport engineers think drivers behave in roadworks and how they actually behave. As a result of this incompatibility we are losing approximately a lane's worth of capacity in addition to those closed by the roadworks themselves. The problem would have little significance were it not for the fact a lane of motorway costs approx. £30 m per mile to construct and £43 k a year to maintain, and that many more roadworks are planned as infrastructure constructed 40 or 50 years previously reaches a critical stage in its lifecycle. Given current traffic volumes, and the sensitivity of road networks to congestion, the effects of roadworks need to be accurately assessed. To do this requires a new ergonomic approach. A large-scale observational study of real traffic conditions was used to identify the issues and impacts, which were then mapped to the ergonomic knowledge-base on driver behaviour, and combined to developed practical guidelines to help in modelling future roadworks scenarios with greater behavioural accuracy. Also stemming from the work are novel directions for the future ergonomic design of roadworks themselves.

1. Introduction

1.1. Background

There is an abundance of anecdotal information about how drivers behave when confronted with roadworks. In some regions of the world drivers will merge seamlessly, like a zip, in order to flow smoothly into a reduced number of lanes. In other regions the conventions which normally govern polite civil society will collapse into chaos as everyone jockeys for position at the front of the queue. In regions like the UK, for example, to avoid the aggression and social exclusion of attempting to 'push in' at the head of a long queue, drivers will merge into a reduced number of lanes some-times miles ahead of the actual lane reduction. Despite this global body of anecdotal experience there is comparatively little practical information about how driver behaviour, and the resulting impact on wider traffic conditions, is affected by roadworks. There are the Minnesota studies examining different queuing and merging strategies (e.g. [Beacher et al., 2004a, b](#)), a reasonable body of literature on safety in roadworks (e.g. [Allpress and Leland, 2010](#); [Bai et al., 2010](#)) and transportation engineering information on capacity,

throughput and other traffic parameters (e.g. [Transportation Research Board, 2000](#)). What none of this work directly con-fronts, however, is a persistent feature of roadworks found the world over: a greater than expected reduction in traffic throughput. According to the Design Manual for Roads and Bridges (DMRB; [Highways Agency, 2004](#)) a lane of motorway is designed to carry in the region of 2000 vehicles per hour, but when roadworks require the number of those lanes to be reduced, the capacity on the still open lanes drops significantly below this value. This feature is so pervasive it is represented in design guidance (e.g. [Transport Research Board, 2000](#)) and has been for many decades. Depend-ing on the number of lanes closed by roadworks, the flow on the still open lanes can reduce by anything between 25 and 40%. Worse still is that the reasons for this reduction are not well understood. What we have, therefore, is an engineered environment where there is an expectation that people will behave in certain ways, except they do not. As a result, this paper argues that roadworks represent a novel applied ergonomics problem. To begin tackling it a large-scale observational study of real traffic conditions was used to identify the issues and impacts, which were then mapped to the ergonomic knowledge-base on driver behaviour, and combined to developed practical guidelines to help model future roadworks scenarios with greater behavioural accuracy. Also stemming from the work are some novel departures from the current state of the art in roadworks best-practice.

1.2. Designing roadworks

Traffic Management (TM) is provided at roadworks for the principle purpose of protecting contractors and plant operating on the site. Its secondary function is to control traffic through the roadworks. Advanced warning signage ahead of the roadworks informs drivers of the works ahead and any action to take, such as reductions in speed, instructions to stay or move lanes, and indications of when to merge and/or turn. Barriers and cones are deployed to temporarily reconfigure the road layout, offer protection to site workers, and provide unambiguous visual cues for drivers to help them know what is expected and what to do. Extensive guidance on how these traffic management measures should be implemented are given in various guidance documents (e.g. [Highways Agency, 2009](#)) and the physical properties of similar interventions have been the topic of ergonomic analysis previously (see [Zhang et al., 2013](#) for a recent example).

Roadworks, and their associated Traffic Management, have an impact on traffic conditions. Given the heavily loaded (often congested) conditions on many strategic road networks these effects can propagate dramatically if not fully understood prior to the work taking place. The method adopted to anticipate these effects, and therefore design and schedule individual roadwork activities, is to undertake traffic microsimulation studies. Traffic microsimulation is a form of agent-based modelling that tries to capture "the actions and interactions of individual vehicles, in simulated time steps typically less than one second, as they travel through a road network. Traditional models [...] assign a matrix of trips to a network calculating average journey times across timeframes of one hour or more, using empirical relationships between flow and theoretical capacity. Through its focus on simulating individual vehicles, microsimulation is capable of providing a real time visual display, which represents the second key distinction compared to traditional models." ([Woods, 2012](#), p. 339) Microsimulation is an increasingly prominent theme in transportation research (e.g. [Farooq and Miller, 2012](#); [Liu et al., 2006](#); [Roorda et al., 2008](#)) and the possibilities it provides for understanding the collective effects of individual driver behaviours are tantalizing (e.g. [Hackney and Marchal, 2011](#); [Casucci, Marchitto & Cacciabue, 2010](#)). A surprising feature of microsimulation (and agent-based techniques in general) is the comparatively limited extent to which they capture the complexities of real human behaviour. The rules governing the simulated behaviours of the modelled vehicles are comparatively simple. Despite this, the collective effects of these simple behaviours are extremely powerful and lifelike, but in order for the robustness of these effects to be tested microsimulation models need extensive calibration. This is the process by which, given the same parameters, a microsimulation model will replicate a known state of affairs. If not, the model parameters need to be iterated and the model re-run until it converges on observed data. The key issue is that if the behaviours of the simulated vehicles could be referenced more closely to what is known about driver behaviour in the ergonomics domain, then the need for extensive model calibration could be significantly reduced. In addition, the possibility of disconnects between actual and modelled driver behaviour, and roadworks are a prominent case in point, can also be reduced. This would mean model predictions would become more accurate and more quickly produced.

In the case of roadworks, government agencies such as Transport Scotland use microsimulation models covering very large geographical areas as a platform for testing proposed roadworks scenarios in a number of future years. For the planning of roadworks in the Glasgow metropolitan area, for example, the Clyde Strategic Microsimulation Model is used ([SIAS, 2011](#)). This model contains 250 km of roads, 1.5 million individual simulated vehicles,

50 grade separated junctions and provides a continuous simulation of traffic conditions over a full 24 h period ([SIAS, 2011](#)). Models like this enable roadworks to be scheduled in optimum ways, and for road users to be provided with accurate information about potential delays before the roadworks have started. As noted above, for models like these to work accurately it is critical to have an understanding of how driver behaviour at roadworks may differ from "normal" circumstances. There is anecdotal evidence that these differences are significant and, if so, the effects on capacity, delays, safety and emissions could also be significant (e.g. [Jin et al., 2008](#); [Khattak et al., 2002](#); [Lee, 2009](#); [Lepert and Brillet, 2009](#); [Li and Bai, 2008](#); [Weng and Meng, 2011](#); [2012](#); [Zhang et al., 2011](#)). The first step, therefore, is to compare the outputs produced by the Clyde Strategic Microsimulation Model with a real roadworks scenario in order to reveal the extent of the issues at hand, before moving on to a review of the ergonomic knowledge base to explain the discovered results and offer solutions.

2. Study of driver behaviour at roadworks

2.1. Arkleston Bridge Strengthening Works

Like many cities around the world, Glasgow (in Scotland, UK) has a strategic road network constructed largely in the 1960's and 70's. Many of the structures are currently 40 or more years old and approaching a phase in their life cycle when critical maintenance and upgrading is required. An example of this was the Arkleston Bridge Strengthening Works, a £1.2 m upgrade which took place between 17th July and 8th September 2009 on the principle route into Glasgow from the West. This case study provides an ideal test of the traffic flows the Clyde Strategic Microsimulation Model predicts will occur in this situation, and the actual traffic flows which emerged when real drivers encountered this engineered environment. The question to be explored is whether people behaved in ways predicted by the model, and if not, to what extent the actual traffic flows differed from those that were modelled.

2.2. Details of the roadworks

The Traffic Management (TM) measures associated with the roadworks were implemented on both the eastbound and west-bound carriageways of the M8 motorway, with full closures and associated diversions implemented during night works. Details of the traffic management scenario are presented in [Fig. 1](#). The Traffic Management measures included a temporary speed limit of 40 mph, reduction of the main carriageway from three lanes to two lanes, and cylinders added to the on-ramp of Junction 26 (J26) to prevent early merging, reducing the effective ramp length by approximately 75%.

2.3. Collection of modelled and observed traffic flows and speeds

The roadworks shown in [Fig. 1](#) were implemented in the Clyde Strategic Microsimulation Model, the model was run 10 times, and the mean predicted traffic flows across each of the 24 h periods averaged. For the real roadworks, actual traffic count data from permanent Automated Traffic Count (ATC) sites within the study area were obtained for the period January 2006 to February 2009. In addition, specific data for the study was gathered from the area local to the Arkleston Bridge Strengthening Works for the remainder of 2009. In order to further establish the impact of the roadworks on traffic conditions, speeds from the ATC sites in the locality of the works were also provided.

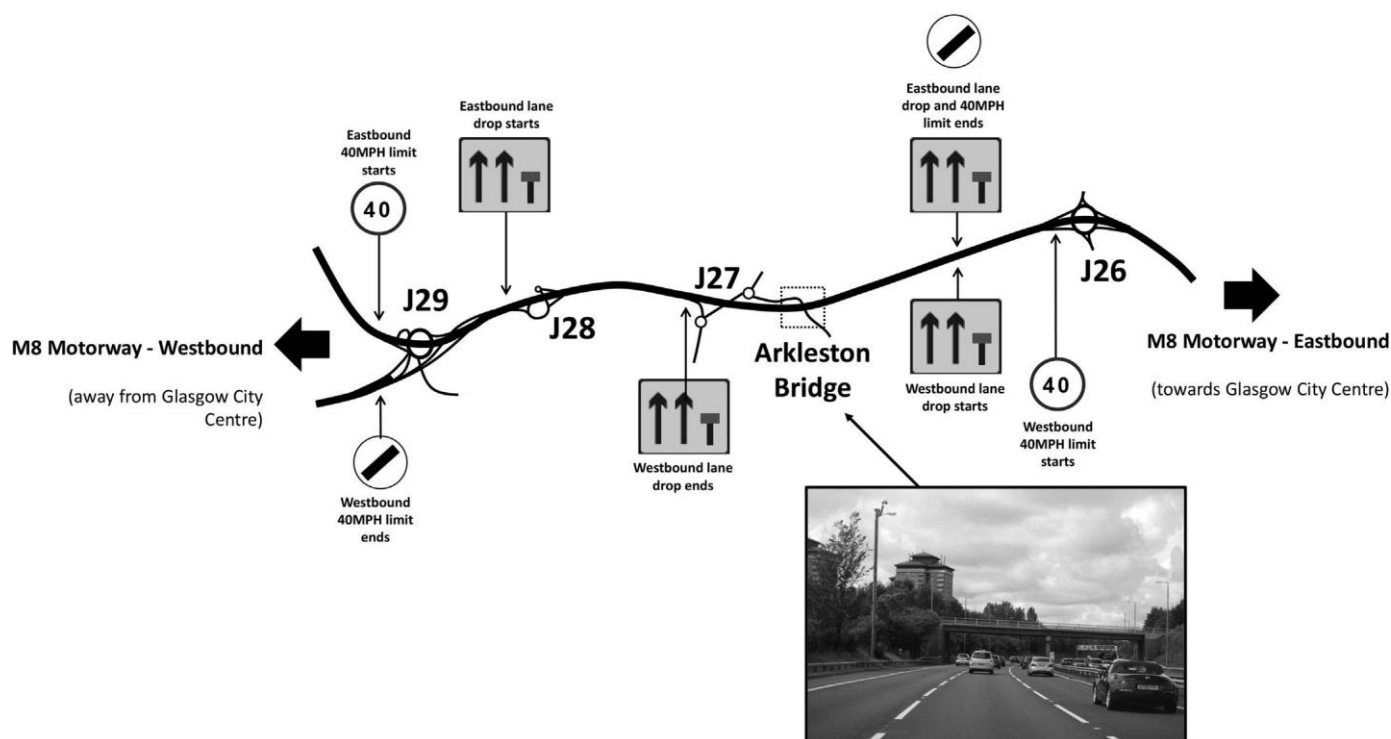


Fig. 1. Details of the live traffic management case study (Image of M8 motorway: Chadwick/Creative Commons).

2.4. Results and discussion

Table 1 and Table 2 show comparisons between observed and modelled flows for the AM (08:00e09:00) and PM (17:00e18:00) peak hours. The GEH statistic has been used for the comparisons and is designed specifically for the comparison of hourly modelled and observed flows (GEH itself refers to the developer's initials; DMRB, Highways Agency, 2004). Both relative and absolute differences are taken into account when calculating the GEH value as follows:

$$GEH = \frac{\delta Vo - Va}{0.5 \cdot \delta Vo + Va}$$

Where Vo = Observed Traffic Flow and Va = Assigned Traffic Flow. The DMRB suggests that a GEH value of less than five represents a satisfactory match between modelled and observed traffic flows.

It can be noted that lower flows are observed in the case study on the westbound carriageway in the AM peak hour, and the east-bound carriageway in the PM peak hour. In these low-flow scenarios the comparisons are generally good, with the GEH values representing a satisfactory match between modelled and observed scenarios (see Figs. 2 and 3). The highest flows in the case study are observed on the eastbound carriageway in the AM peak hour, and the westbound carriageway in the PM peak hour. Tables 1 and 2 indicate that the comparison of modelled and observed flows is poor for these critical flows. In general, the modelled flows are generally much higher than the observed flows. The flow on the M8

Table 1

Observed and modelled traffic flow comparisons at the Arkleston Bridge Strengthening Works during the AM peak hour. A GEH value of five or more indicates an unsatisfactory match (shaded cells) between observed and modelled flows. Unsatisfactory values are summed to give an indication of the capacity being lost.

Description	Observed from traffic counters	Modelled using microsimulation	Difference	GEH
Eastbound (towards city centre)				
M8 West of J29	1530	2230	699	16.1
A737 to M8	1850	2316	466	10.2
M8 before J28	2778	4146	1368	23.3
M8 J27 off ramp	299	629	330	15.3
M8 J27 on ramp	729	490	240	9.7
M8 J27 e J26	4022	4308	286	4.4
Total capacity reduction			2625	
Westbound (away from city centre)				
M8 J26 e J27	3527	3513	14	0.2
M8 J28 Off slip	647	875	228	8.3
M8 J28 e J29	2698	2754	56	1.1
M8 to A737 Sb	900	826	74	2.5
M8 off slip to J29	473	482	9	0.4
M8 through J29	1244	1407	163	4.5
Total capacity reduction			228	

Table 2
Observed and modelled traffic flow comparisons at the Arkleston Bridge Strengthening Works during the AM peak hour. A GEH value of five or more indicates an unsatisfactory match (shaded cells) between observed and modelled flows. Unsatisfactory values are summed to give an indication of the capacity being lost.

Description	Observed from traffic counters	Modelled using microsimulation	Difference	GEH
Eastbound (towards city centre)				
M8 West of J29	2270	2207	63	1.3
A737 to M8	1032	1147	115	3.5
M8 before J28	2738	2836	98	1.9
M8 J27 off ramp	565	513	52	2.2
M8 J27 on ramp	601	709	108	4.2
M8 J27 e J26	3365	3517	152	2.6
Total capacity reduction			0	
Westbound (away from city centre)				
M8 J26 e J27	3488	4772	1283	20.0
M8 J28 Off slip	410	596	186	8.3
M8 J28 e J29	3831	4587	756	11.7
M8 to A737 Sb	2104	2354	250	5.3
M8 off slip to J29	360	493	133	6.4
M8 through J29	1290	1658	368	9.6
Total capacity reduction			2976	

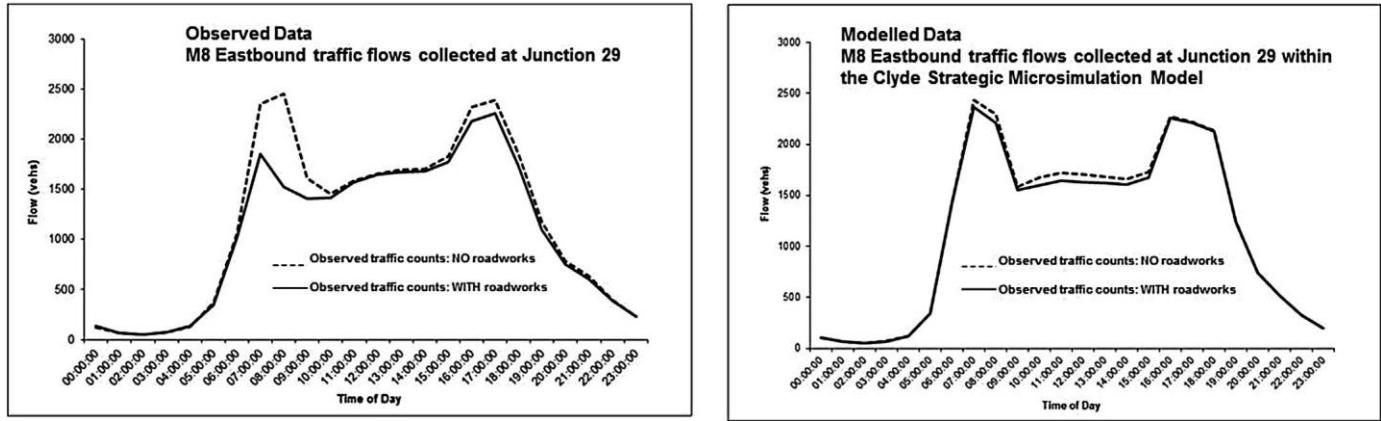


Fig. 2. Traffic flow comparison over 24 h period. The left-hand chart shows the observed traffic flows with roadworks in place (solid line) and without roadworks (dotted line). The right hand chart shows the modelled traffic flows with roadworks in place (solid line) and without (dotted line). A significant discrepancy in morning peak flows is evident in the observed data but not the modelled data.

Eastbound approaching J28 in the AM peak hour, for example, is around 1300 vehicles too high, resulting in a GEH value of 23.3.

Figs. 2 and 3 show the profile of observed and modelled traffic flows, for both directions, with and without the roadworks, over a

full 24 h period. Both Figures show that in the inter-peak periods, when traffic flows are relatively low, the modelled flows match well with the observed. In the AM peak period, however, the east bound modelled flows are significantly higher than the observed whilst in

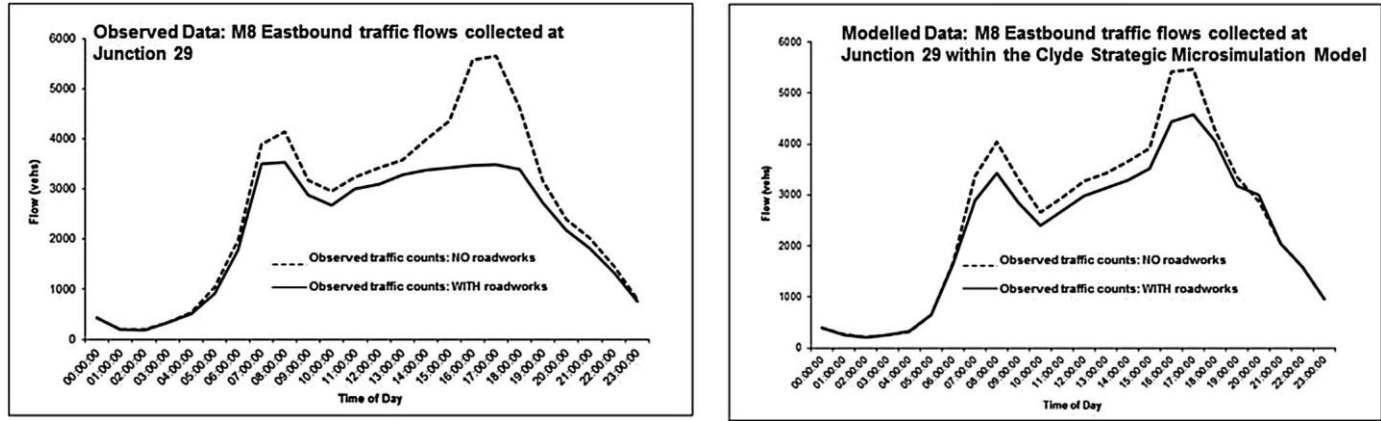


Fig. 3. Traffic flow comparison over 24 h period. The left-hand chart shows the observed traffic flows with roadworks in place (solid line) and without roadworks (dotted line). The right hand chart shows the modelled traffic flows with roadworks in place (solid line) and without (dotted line). A significant discrepancy in evening peak flows is evident in the observed data but less so for the modelled data.

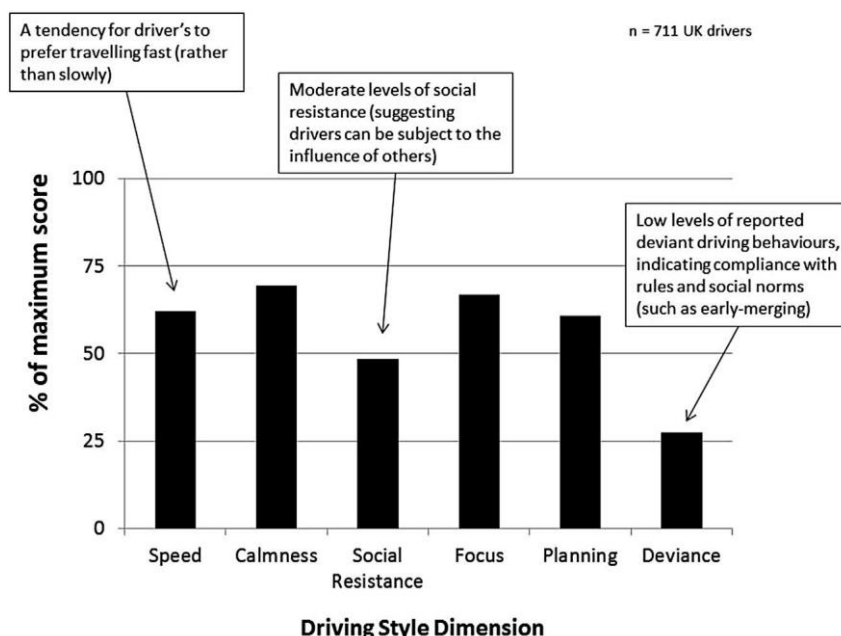


Fig. 4. Results of a large scale study into driving style reveals the following profile. Adapted from French et al., 1993.

the PM peak period the west bound modelled flows are significantly higher. In other words, at critical times of day the Clyde Strategic Microsimulation Model is predicting more traffic will pass through the roadworks than is actually the case. Closer inspection shows that the worst mismatches between modelled and observed flows, those with the highest GEH, are occurring some distance before the actual roadworks site in the vicinities of J29 (0.86 km away from the onset of the lane drop) and J26 (1.17 km away). Observations made at these locations confirm that early merging is taking place, and for considerable distances further back in the traffic stream, leading in turn to the significant reductions in traffic flow.

The results show clearly a marked discrepancy between modelled and observed flows, and the associated driver behaviour. Is this typical? Tables 3 and 4 suggest it is.

According to the Highway Capacity Manual (2004) the average capacity reduction with two lanes open from a total of three is 25%. The observed data from the Arklestone Bridge Strengthening Case Study shows an average capacity reduction (also with two lanes open from a total of three) as 21.75%, although this peaks in some traffic count locations as high as 55%. If both directions of travel are taken, and the mean (not peak) reduction in traffic flow on the two still open lanes of traffic is used, then it adds up to approximately 2000 vehicles per hour. This is the notional capacity of a lane of motorway (e.g. Highways Agency, 2004), and it is being lost due to driver behaviour factors. Reference to Tables 1 and 2 suggests this

may be a conservative estimate. More important is that the current modelling approach is not sufficiently representing the driver behaviour which gives rise to this problem. The following sections undertake to examine the underlying reason for this based on the Ergonomics literature, and to combine the insights from the case study and the prior knowledge-base to offer some practical solutions.

3. Ergonomic issues

3.1. Representing driver behaviour

From the previous analysis there is clearly a problem with driver behaviour at roadworks. Capacity on the open lanes is

Table 4
Mean open-lane capacity for Arklestone Bridge Strengthening Works Case Study.

M8 Case Study			
Total	Open	% Of total lanes available	% Capacity reduction from pre-works situation
3	2	66%	21.75% (Mean) 55% (Max) 6% (Min)

^a M8 J27 off ramp Eastbound.

^b M8 Eastbound West of J29.

Table 3
Mean open-lane capacities for different combinations of lane closure.

No. of lanes		Highway Capacity Manual 2004		
Total	Open	% Of total lanes available	Average capacity (vphpl)	% Capacity reduction from notional 2000 vphpl
4	3	75%	1520	24%
3	2	66%	1490	25%
4	2	50%	1480	26%
2	1	50%	1340	33%
5	2	40%	1370	31%
3	1	33%	1170	41%

substantially reduced, even though in other 'normal' lane-drop situations this is not the case. When faced with a roadworks situation in which traffic is expected to merge into a reduced number of lanes, the simplest manifestation of transportation engineering theory is predicting the following: the available lanes will become fully occupied on an 'All Or Nothing' (AON) basis. Individual drivers will elect to travel in the lane that has the lowest cost to them in relation to various economic factors such as travel time. Parameters such as travel time change rapidly in response to live travel conditions and, according to the rubric of AON, so will driver behaviour. Through these means the traffic stream will, according to this strict interpretation of transportation engineering theory, organise itself so all available lanes will become maximally loaded. As the data in the previous section indicates, this is not the case in practice. The effects observed in real-life situations strongly suggest that other, more complex processes are in play. A simple approach to behaviour at road works does not take account of multiple personal and systemic factors that influence driver behaviour, specifically:

The fact drivers do not have complete information on cost variables in order to make an optimum decision (e.g. Dogan et al., 2011).

Even if they did have complete information, an optimum decision at an individual level will be guided by other, non-engineering motivations and objectives (e.g. Sivak, 2002).

The roadworks situation represents a change in the driver's perceptual environment and this, in turn, interacts with driver expectations, allocation of attention and decisions about expected and required behaviour.

Driver behaviour at the collective level of the total traffic stream affects how individual drivers will behave.

And finally, behaviours taking place in a TM situation are culturally embedded (i.e. cars that are arranged in a line are in a queue and there are expected norms and standards of behaviour governing how people 'should' queue).

The following sections take the insights provided by the study of observed and modelled driver behaviour, and bring to bear the ergonomic knowledge-base to try and understand better why a mismatch emerges. The focus is on the factors that influence driver behaviour before and on the approach to a Traffic Management (TM) situation, as it is during these phases that the problem of reduced capacity seems to arise. This represents a different focus to the majority of literature on roadworks, which tends to highlight the circumstances immediately prior and within the TM site (e.g. Allpress and Leland, 2010; Heaslip and Collura, 2009; Huang and Shi, 2008; Morgan et al., 2010; Sorock et al., 1996; Whitmire et al., 2011). By surveying the knowledge-base in this way it then becomes possible to offer practical solutions.

3.2. Driver behaviour before roadworks

At this point in the analysis timeline drivers are established in a traffic stream well in advance of a roadworks situation. Several psychological factors relevant to subsequent driver behaviour are already present in the traffic stream: there are expected standards of behaviour, social norms, and future outcomes with aversive emotional outcomes that drivers wish to avoid. There is also the powerful effect of other drivers. Specifically, how their behaviour can influence individuals and, in turn, feedback into the entire traffic stream. Then there is the effect of driving style, something that drivers bring to the driving scenario and which feeds into the wider 'social psychology' of driving.

3.2.1. Unwritten rules of the road

In addition to economic factors such as cost and utility, driver behaviour is also governed by norms or collective expectations "that define the boundaries of appropriate social behaviour in particular settings" (Manstead and Semin, 2001). Collective similarities in driver behaviour are well established in the scientific literature: sounding the horn to communicate annoyance to other road users is more prevalent in Greece and Turkey than it is in Finland and Sweden (Warner et al., 2011), for example, or fewer 'aggressive violations' are performed by Finnish, British and Dutch drivers compared to those in Iran (Lajunen et al., 1999). The wider collection of norms that help to define the boundaries of social behaviour in all its aspects is referred to as culture. Culture is formally defined as: "The system of information that codes the manner in which [drivers] in an organised [traffic stream] interact with [other drivers] and [the road] environment" (Reber, 1995, p. 177). Culture is important in a transportation engineering context

because it is linked to behaviour (e.g. Elliott et al., 2005; Ozkan et al., 2006). The dominant model that describes this culture-behaviour relationship is the Theory of Planned Behaviour (Ajzen, 1991).

Under the Theory of Planned Behaviour the main determinant of actual driver behaviour is an intention to perform it, for example, "I am going to move into the inside lane at the earliest opportunity". Of course, drivers do not perform every behaviour they intend to perform because of the modifying influence of other factors. The first of these modifications takes place when the intention to perform a behaviour is subject to a negative or positive evaluation, or in other words, the driver's attitude towards it is brought to bear. Attitudes are informed by beliefs and expectations that certain positive or negative outcomes will arise in the future, so for example, "if I get into the inside lane early I won't get stranded in the outside lanes". These beliefs, in turn, are further modified by the driver's assessment of whether the intended behaviour corresponds to acceptable behavioural norms in the eyes of other people: "if I don't get into lane one early then I will invite a lot of unwanted attention and aggression from other drivers, who will think I am trying to push-in". A critical point is that expectations of negative emotions (such as unwanted attention/aggression from other motorists) have a significantly adverse effect on whether a behaviour is performed, often despite 'objective' evidence to the contrary such as explicit instructions to 'use both lanes' or 'merge in turn' (Roca et al., 2012).

The Theory of Planned Behaviour has been used in numerous transportation contexts before (e.g. Elliott et al., 2005; Palat and Delhomme, 2012; Paris & Van den Broucke, 2008 etc.) and is pre-mised on the idea that in order to change behaviours a worthwhile strategy is to understand the underlying beliefs and target them (rather than the behaviour itself). Analysis of these underlying beliefs is typically accessed via questionnaire and/or survey methods such as the Driving Style Questionnaire (French et al., 1993), Driver Behaviour Questionnaire (Lajunen et al., 1999) and others. This prior research can be usefully applied to the problem of TM in order to reveal underlying culture-belief-behaviour relationships and target them effectively.

3.2.2. The effect of other people in the traffic stream

Addressing the issue of roadworks from a cultural perspective helps to foreground the role of driver's beliefs in future states and the opinions of other people in the immediate traffic stream. Driving is clearly a 'social' activity that is performed in close proximity to, and to varying degrees in close cooperation with, other drivers (Fleiter et al., 2010). In motorway/freeway driving in particular, the presence of other drivers is very important. Research shows that in this setting a large component of driver situational

awareness is devoted to the behaviour of other motorists (e.g. Walker et al., 2013; Engstrom et al., 2005) and that drivers' attention-level is closely related to their use of the rear view mirror (Pastor et al., 2006). These effects do not occur on lesser-classes of road, thus the 'social' aspect of motorway/freeway driving is particularly marked.

If other motorist's behaviour in this environment is important then so are the expectations and beliefs about how those 'other people' view 'your' behaviour. How individual drivers present themselves to others has been shown to have an important inhibiting or amplifying effect on behaviour, to such an extent that it can be a more powerful determinate of driver behaviour than other environmental, engineering and even enforcement-based interventions (Havarneanu[^] and Havarneanu, 2012; Edwards, 1999). The effect of other people's views on individual behaviours is referred to as conformity: "the tendency to allow one's opinions, attitudes and actions and even perceptions to be affected by pre-existing opinions, attitudes, actions and perceptions" (Reber, 1995, p. 152). Evidence for the effect of collective, conformity-based behaviours can be seen in numerous transport studies. Drivers behave differently approaching junctions when following, or being followed, by others; they tend to go faster and brake later (e.g. Sato and Akamatsu, 2007; Ranney, 1999; Yousif and Al-Obaedi, 2011). In large traffic streams such as those found on congested motorways/freeways, the influence of surrounding traffic gives rise to inadequate speed adaptations in poor weather. Drivers feel under pressure from other drivers to keep up and do not slow down sufficiently when it is wet (Edwards, 1999; Brackstone et al., 2002; Brackstone et al., 2009). Numerous studies highlight this social pressure from others, whether actual or inferred (e.g. Fleiter et al., 2010) and it is highly relevant to the problem of roadworks. Some forms of social pressure work in favourable inhibiting directions (e.g. people that the driver knows, such as passengers, tend to inhibit speed; Fleiter et al., 2010) whilst in other situations, with 'anonymous other drivers', it has the reverse effect (e.g. early-merging in response to upcoming TM).

It has been observed that certain driver behaviours follow a form of 'contagion' model. Drivers tend to underestimate the speed of anonymous others (e.g. Walton and Bathurst, 1998; Redelmeier and Tibshirani, 1999), yet they wish to conform to what they perceive is the behavioural norm. Because drivers underestimate the speed of others they tend to increase their own speed too much in order to do this, which other drivers, who also want to conform to the behavioural norm, also underestimate, and so the entire traffic stream tends to speed up (Connolly and Aberg, 1993). Similar contagion effects are evident for other driver behaviours, such as blocking late mergers from joining a queue at the front.

At the root of contagion models of behaviour is the need to conform to what are perceived as acceptable standards of behaviour and to avoid the negative consequences of social rejection. In a transport context social rejection would take the form of a break-down in cooperative behaviours, with other drivers rejecting attempts to change lanes, becoming aggressive and demonstrating negative feelings. Social rejection also brings with it negative feelings of embarrassment, a mismanaged self-presentation in which other drivers will make 'errors of attribution'. Attribution can be defined as "a tendency of people observing the action of another to interpret those actions as a sign of, or as resulting from, an internal disposition or trait" (Reber, 1995, p. 68). Because of attribution, drivers will follow large trucks at shorter headways based on "a popular belief that truck drivers (being professionals and having their livelihood depend on their driving, or more accurately, their accident avoiding skills) are less likely to misjudge any situation, anticipating and 'reading' the road far earlier and more accurately than any car driver." (Brackstone et al., 2009,

p. 140). Further research shows the perceived status of the 'horn honker' (an attribution based on the vehicle being driven) determines the length and duration of the 'honk' (Doob and Gross, 1968), drivers of large four-wheel drive vehicles engage in different, sometimes more risky behaviours than drivers of 'normal' cars (e.g. Bener et al., 2008) and that there are age-related differences in skill (e.g. Borowsky et al., 2009), and so on.

In research on aggression it is clear that attribution errors, whereby behaviours are seen to refer to traits exhibited by certain 'types' of individuals, frequently lead to self-presentation failures and the elicitation of aggressive responses (e.g. Walters and Cooner, 2001). Drivers actively seek to avoid aversive emotions such as embarrassment or aggression (e.g. Schmidt-Daffy, 2013). To do this they seek to control the way other drivers perceive them by exhibiting some behaviours (i.e. conforming to what the rest of the traffic stream is doing) whilst suppressing others (i.e. ignoring instructions to do something different such as 'late-merge'). This phenomenon is not well studied in the driving domain. It is certainly the case that the need to project a particular image of oneself, through particular driving behaviours, is undertaken to avoid failures in self presentation. This offers an explanation for the reluctance of drivers in roadworks situations to late-merge; they do not want to be perceived as 'the type of driver' who would do that which, in many countries, would be an inconsiderate, disrespectful or ignorant type of driver. Social Learning (Akers, 1998) provides a further explanation for how collective driving behaviours like these feedback into the wider 'driving culture', to themselves become norms and expected standards of behaviour for everyone in the traffic stream to conform to.

3.2.3. Driving styles

Another approach is to consider decision making style, or the "way individuals habitually approach decision problems and use information" (French et al., 1993, p. 627). A long standing research goal has been to extract situationally independent measures of decision making style, and to relate these to accident rates and other indicators of actual driver behaviour. Measures such as the Driving Style Questionnaire (DSQ; French et al., 1993) and Driver Behaviour Questionnaire (DBQ; Lajunen et al., 1999) have resulted from this research and in the course of their development numerous insights into population-wide driving style parameters have been revealed. The Driving Style Questionnaire (DSQ), for example, grants access to six parameters, all of which correlate significantly with accident rates and behaviours. These are:

1. Speed: "do you drive fast [through road works]?"
2. Calmness: "Sometimes when driving, things [like road works] happen very quickly. Do you remain calm in such situations?"
3. Planning: "Do you plan long journeys in advance [and know where TM is taking place]?"
4. Focus: "Do you find it easy to ignore distractions [related to TM situations?] while driving?"
5. Social resistance: "Is your driving [in road works] affected by pressure from other motorists?"
6. Deviance: "Do you overtake on the inside lane of dual car-riageway [or push in at the head of TM queues] if you have the opportunity?"

In a study of 711 UK drivers the extent to which these factors were present in the traffic stream is revealed to be as follows (French et al., 1993) (see Fig. 4):

The findings for driving style, if they are assumed to hold for an entire traffic stream, suggest certain tendencies towards driving fast (rather than slowly) and fairly modest levels of social resistance (suggesting a tendency to be influenced by others). Research by

Sun and Eleftheriadou (2011) goes further to suggest four distinct categories of drivers each associated with a different form of lane changing behaviour. The first category "always want to keep to the current lane because they are risk averse" and would "likely give way to vehicles merging into the current lane, or try not to block others" (p. 686e7). The second category of driver "would like to get a better position or speed advantage for some situations under very low risk, but wouldn't on others" (p. 687). The third category of driver "aim[s] to get a better position or speed advantage if they have a chance. However, they would also consider other factors, such as traffic congestion or destination, which they consider more important than speed advantage and better positioning." (p. 687). The fourth and final category of driver "would always try to get a better position or speed advantage whenever they have a chance. They barely think about other drivers. Position and speed are their first consideration." (p. 687). These, then, are 'situationally independent' indicators of decision making style that drivers bring with them to roadworks sites which, in turn, could be helpful in defining behaviour change strategies. Some strategies could foreground reductions in risk, others could foreground advantage in terms of position or journey time.

3.3. Driver behaviour approaching roadworks

The approach to roadworks sites sees the various latent driver behaviour factors resident in the traffic stream become active. Driver's situational awareness prepares them to take notice of what other traffic is doing, with norms and expected standards of behaviour encouraging some behaviours and inhibiting others. Driving style preferences towards greater (rather than lesser) speed influences the behaviour of other drivers, who 'feel under pressure from others' due to low levels of social resistance. Social norms that dictate acceptable behaviours in queuing situations also come into play with drivers trying to avoid 'social exclusion' and 'attribution errors'. As a result, despite engineering interventions such as signs, and enforcement interventions such as speed cameras and police patrols, the typical situation, in the UK at least, is one where drivers move into the desired travel lane too early. This so-called 'early merge' phenomenon is what reduces capacity and throughput significantly as evidenced in the previous case study.

3.3.1. Effects of congestion

Roadworks often create congestion. This has the effect of changing an important facet of the driving environment; it places more 'other drivers' in closer proximity, thus activating powerful social processes which affect behaviour (e.g. Wang et al., 2009). In addition to this, driver's intentions to perform the behaviours they intend to perform are increasingly thwarted by the proximity of other vehicles and a more crowded road-space. This, in turn, leads to elevated levels of frustration within the traffic stream.

The frustration-aggression hypothesis puts forward the idea that when drivers experience frustration they will exhibit aggression in the form of action aimed at harming another person (Shinar, 1998). In the case of driving this spans the full range of aggressive acts, from refusing to allow another driver into a queue of traffic (Walters and Cooner, 2001) through to extreme acts of so-called 'road rage' (e.g. Joint, 1995). Anger and aggression in driving is common. When surveyed, in the region of 80e90% of drivers re-ported some form of aggressive behaviour, from sounding the horn through to chasing other drivers (e.g. Parker et al., 1998; Under-wood et al., 1999; Gonz_alez-Iglesias et al., 2012).

Certain environmental conditions are required for particular aggressive acts, conditions that the congestion and queuing in advance of roadworks sites provides. The first of these is the effect of crowding. Evidence is mixed but it is clear that increased traffic

densities lead to greater extents of thwarted behavioural in-tentions. This has been shown in some studies to increase aggressive acts and/or behaviours related to exiting from the situation entirely (from late merging to revised travel plans; Baron and Richardson, 1994; Shinar, 1998). The second condition is related to aversive arousal or the experience of negative emotions, and the way this leads people to avoid or react to situations that give rise to them (e.g. Schmidt-Daffy, 2013). One of the principle ways in which congestion and queuing at TM sites gives rise to aversive arousal is in respect to elevated levels of anxiety, some key reasons for which are presented below:

3.3.2. The psychology of queuing

Drivers are notoriously intolerant of having their intention to 'drive' (or move forward towards their destination) thwarted, despite showing high levels of 'wait tolerance' in other settings (Maister, 1985). This gives rise to marked peculiarities in prefer-ences, such as drivers preferring a more congested (i.e. slower) mainline flow than a longer wait at a ramp meter (Levinson et al., 2006; Wu et al., 2007), or considering approximately two mi-nutes to be the maximum acceptable waiting time at railway level crossings, with 18% of drivers willing to drive around the barriers after 15 min (Ellinghaus and Steinbrecher, 2006). Pioneering studies in consumer psychology reveal specific sources of anxiety arising from queues (Maister, 1985; Mann, 1970). These are sum-marized in Table 5.

For the reasons discussed above, advice targeted at driver be-haviours which are aimed at increasing the efficiency of roadworks will not always be followed. This is not to say drivers are unaware of signs and instructions (e.g. Bai et al., 2010; Horberry et al., 2006; Beacher et al., 2004a, b etc.) more that these social psychological factors intervene to significantly attenuate the desired response (Havarneanu[^] and Havarneanu,[^] 2012; Long et al., 2012). This being the case, what strategies could be employed to directly alter driver behaviour at roadworks?

4. Influencing driver behaviour at road works

4.1. Experiments in early and late merging

A number of studies have been performed to analyse the relative benefits of different merging strategies in advance of TM sites. These strategies are defined broadly as follows:

The early-merge strategy: This follows work performed by the Indiana Department of Transport and is a system which "en-courages drivers to merge into the open lane sooner than they usually would and before arriving at the end of a queue" (Hossinger€ and Berger, 2012, p. 153). The rationale behind this strategy is that by organising the traffic stream well in advance of the lane-drop it avoids the problem of 'disruptive flow' caused by late merging, and the concomitant problems of accidents and driver frustration.

The late-merge strategy: This follows work performed by various other US Departments of Transport (notably Pennsylv-ania and Minnesota) and is a system which "encourages drivers to stay on the open or dropping lane until they reach the merge point" (Hossinger€ and Berger, 2012, p. 153). The rationale behind this strategy is that more of the available road space can be used for queue storage, reducing queue length and driver frustration.

Neither of these strategies is ideal in all circumstances, and it is important to note that the studies are based on US urban roads (not motorways) with the associated norms, driving styles and beh-aviours therein. The early-merge strategy reduces the number of

Table 5
Sources of queue anxiety (from Maister, 1985).

Occupied time feels shorter than unoccupied time
Waiting in a traffic queue is 'unoccupied time' that cannot be easily filled with other useful or distracting activities. The perception of time is entirely subjective and influenced by emotional states such as frustration. An unoccupied wait in a traffic queue increases the onset of driver frustration and anxiety, an aversive emotional state that drivers will try to avoid.
Drivers want to get started
The early merge phenomenon leads to queues that are often longer than the overt signs of a roadworks site. This means that for waiting drivers the cause of the queue (i.e. the road works) is not always evident and the experience of the roadworks has not yet begun. Put another way, "pre-process waits are perceived as longer than in-process waits" (Maister, 1985, p. 4) meaning that waiting tolerance increases once drivers are actually 'in' the road works.
Anxiety makes waits seem longer
'Choosing the right queue' is a significant source of anxiety and a major factor in the early merge phenomenon. Drivers seek to avoid anxiety through a process of 'anticipated regret'. They anticipate the negative consequences of late-merging (e.g. the opprobrium of other drivers) and this serves as a disincentive to change their behaviour from an early-merge strategy. This process is referred to specifically as hyperbolic discounting. Drivers are willing to accept a lesser reward that arrives more quickly (i.e. immediate reduced anxiety arising from early-merging) rather than a bigger reward that will happen later (i.e. potentially faster journey times, but more anxiety via late-merging).
Uncertain waits are longer than known, finite waits
Another significant source of anxiety is how long the wait will be, and evidence suggests that drivers prefer longer definite waiting times (i.e. "delay of ten minutes") rather than vague queue information (i.e. "congestion ahead"). Creating an expectation, however, can be problematic when it is not met (Maister, 1985). Anxiety increases rapidly once the ten minutes of advertised wait time passes, for example.
Unexplained waits are longer than explained waits
Anxiety and frustration levels will be reduced if drivers can be made to understand the causes of their delay. "The lack of an explanation is one of the prime factors adding to a [driver's] uncertainty about the length of the wait" (Maister, 1985). Another key fact is simply that 'waiting is demoralising'; waiting in ignorance more so. Indeed, an important source of frustration is a driver having their status as 'a paying customer' diminished, with aggressive behaviours often being an attempt to re-establish this status.
Unfair waits are longer than equitable waits
"The feeling that somebody has successfully 'cut in front' of you causes even the most patient customer to become furious" (Sasser et al., 1979). This is a particular problem in motorway traffic streams. A powerful illusion is created by the fact that drivers spend more time being overtaken than they do overtaking, thus giving rise to the faulty perception that other travel lanes are moving faster even though the 'average' speed across lanes is approximately equal (Redelmeier and Tibshirani, 1999). The design principle to be extracted from this is that "whatever priority rules apply, the service provider must make vigorous efforts to ensure that these rules match the [driver's] sense of equity, either by adjusting the rules or by actively convincing the [driver] that the rules are indeed appropriate" (Maister, 1985, p. 7).
The more valuable the 'service' the longer the driver will wait
Drivers will find waiting for something of little value, such as permission to continue on what will likely be a similarly congested and unsatisfying journey, to be particularly intolerable (Maister, 1985). In other words, the subsequent level of service often has low value to drivers and this is often reflected in the strategies they will employ in recurring situations like this. Studies reveal, for example, that drivers faced with congestion "will progress from lower-cost, short-term strategies to higher-cost, longer-term ones as dissatisfaction persists or recurs (Raney et al., 2000, p. 141). This offers some insight into anecdotal observations that 'lane blocking behaviour' only emerges later in time, in response to high-cost strategies such as late merging becoming more popular among the queuing traffic.

traffic conflicts but reduces capacity by approximately 5% (McCoy and Pesti, 2000). The late-merge strategy is more effective at peak times, but there is evidence in off peak times that drivers arrive at the lane-drop more quickly (which is potentially hazardous) and that the strategy is affected by the number of heavy goods vehicles in the traffic stream. It is for this reason that Australian studies have tested the feasibility of moving from a 'static strategy' of implementing either early or late merging, to a 'dynamic strategy' of switching between the two. For example, early-merging can be encouraged during off peak times and late-merging in congested peak conditions. The important point to note is that for the social psychological reasons above, the effects of these strategies when applied to other contexts are far from assured. With that in mind the following key results from early/late/dynamic merge studies can be presented in Table 6 (drawn from Beacher et al., 2004a, b):

The body of evidence in favour of different merging strategies is far from resolved and is clearly highly contingent on contextual and

wider social psychological factors of the sort discussed in this re-view. On the other hand, the headline finding is that every form of intervention is superior to the 'do nothing' control condition and that considerable gains seem to be achieved with a mixture of hard and soft engineering.

5. Conclusions

The findings of this research identify the strong influence that social psychological factors have on driver behaviour. The research also shows that roadworks scenarios tend to increase the strength and likelihood of these factors occurring. None of this would be a concern were it not for the fact that it results in significantly different traffic conditions to those that are predicted. In effect, somewhere in the region of an extra lane of capacity is lost due to these 'soft' driver behaviour factors alone. With an increasingly pressing need to adequately model the effects of large scale

Table 6
Results of different merging strategies compared to the 'do nothing' control condition, based on five empirical studies.^a

Output variable	Control condition	Late merge		Early merge	
		Static	Dynamic	Static	Dynamic
Capacity (vehicles per hour)	1390	1730	1820	No data	1540 ^b
Forced Merges	20/hr	5/hr	No Data	Decreased	1/day
Lane Distribution	n/a	30% volume increase in closed lane	No Data	12.4% increase in open lane	20% increase in open lane
Mean Speed (vs. Control Condition)	n/a	7mph decrease (uncongested)	No Data	16.1mpg decrease (uncongested)	2mph decrease (uncongested)
Queue Length	n/a	32mph decrease (congested)	No Data	No Data	No Data
		Up to 50% decrease			

^a Table source: Beacher et al., 2004a, b, based on data from Walters and Cooner, 2001; Bernhardt et al., 2001; McCoy et al., 1999; McCoy and Pesti, 2000; Tarko and Venugopal, 2001.

^b Conflicting data: 5% capacity reduction observed in one study.

maintenance interventions on ageing infrastructure, these effects have to be captured more accurately.

5.1. Ergonomic guidance for modelling driver behaviour at roadworks

Creating microsimulation models which assume traffic re-ponds to roadworks in the same way it responds to other 'normal' situations leads to inaccuracies in the model outputs. Modelled drivers do not differentiate between a roadworks layout and the same layout in 'normal' circumstances, whereas drivers in real-life do make this distinction. It is important to understand how these modelled drivers do behave before considering ways to amend that behaviour in real roadworks scenarios. The previous sections have confirmed the presence of this phenomenon and its severity, and the review of the knowledge-base now enables us to put forward concrete guidance for transport modellers based on features of microsimulation which can be adjusted to give the desired effects. All models require calibration but the aim of these ergonomic guidelines is to help transport modellers reach a calibrated state more quickly. This has been confirmed through initial tests.

5.1.1. Predetermining a modelled flow

The findings of the literature review and the differences between the observed and modelled flows in the case study, suggest there is a correlation between the reduction in flow per lane and the reduction in the number of lanes as a result of roadworks. One approach to modelling, albeit a blunt one, would be to focus on the reduction in flow and use simple modelling techniques to represent this reduction. For example, a model could assume an additional flow reduction of 21% per lane (as found) and ensure that at the highest flows this reduction was achieved. This method, although crude, would not involve any further software development and would result in a more accurate model.

5.1.2. Driver response to TM signage

In the Clyde Strategic Microsimulation Model (CSMM), and others based on the same underlying software, each change in the network (e.g. a reduction in the number of lanes available to drivers) is projected upstream. The modelled drivers, therefore, become aware of a change and are able to react to it before they reach it. The distance a change can be projected upstream can be defined by the programmer. When a modelled driver becomes aware of a change in the network they make a decision about what they want to do. In the case of the Arklestone Bridge Strengthening Works, if a driver is in the outside lane and becomes aware that this lane will close further downstream they will decide to move into an open lane on the inside. In uncongested conditions this manoeuvre is relatively straightforward as there is plenty of road space for the driver to complete the manoeuvre. In congested conditions a driver may be unable to find the road space which enables them to move to an inside line. This is when the critical difference between the modelled behaviour and observed behaviour in roadworks occurs. In the model, if the driver is unable to move from the outside lane to an inside lane they will carry on in the outside lane and continue to assess whether their desired manoeuvre is possible. This will last until the driver reaches the closed lane and has no choice but to move into an inside lane. In effect, then, the model leads to late merging behaviours which, due to the social psychological reasons dealt with in this paper, do not emerge in practice.

In real-life drivers will tend to stop and wait for another driver in the inside lane to let them in, often much earlier than the merge point itself. This illustrates the difference between observed and modelled driver behaviour is not primarily to do with a driver's awareness of the roadworks (and therefore not primarily to do with

the roadworks signage itself) but rather how a driver behaves in response to their awareness. The findings of the literature review, and the differences between the observed and modelled flows and speeds approaching the Arklestone Bridge Strengthening Works, both strongly suggest that in congested conditions drivers get into lane significantly in advance of any signs informing them of lane closures. In other words the awareness of the roadworks in congested conditions may come via the observed queue rather than the signage.

A concrete way to represent this behaviour in the model would be to assume that drivers were aware of the roadworks before they reached the signage for it. This can be achieved in the micro-simulation model by increasing the signposting distance beyond the distance specified in the design of the traffic management. This would result in drivers being aware of the roadworks earlier but would not necessarily result in a change in their behaviour (as it depends on the amount and proximity of other traffic).

5.1.3. Amending modelled driver behaviour

The most robust approach to modelling driver behaviour at roadworks would be to robustly represent the social psychological factors discussed in this paper. The impact of this in modelling terms would be as follows: if a driver is unable to find the road space which enables them to move to an inside lane they would wait for the opportunity to do so, rather than carry on in the outside lane and continue to assess whether their desired manoeuvre is possible. In future it may also be possible to apply different levels of 'social resistance', 'queuing norms', and other features dependent on the region the model is representing. This will require further translational results between research in driver behaviour and the software development underlying traffic microsimulation, but the possibilities are potentially significant.

5.2. Future work

Microsimulation is an exciting tool that grants access to emergent phenomenon not previously accessible from engineering or ergonomic tools. It has great potential to lift the kind of experimental work on driver behaviour more common in the ergonomic domain out of the laboratory, and apply it within a wider system of interacting agents to see what the collective, rather than individual, effects are. Of course, microsimulation alone is not the solution to all transport problems but it is certainly possible to imagine a future whereby more (rather than fewer) human sciences insights become embedded in models like these and tested. Likewise, emergent behavioural phenomena which occur in micro-simulations could help to inform the kinds of studies that could be performed in driving simulators or on-road. What this paper has tried to show is that the coupling between the disparate fields of ergonomics and transport modelling is more achievable than it might first appear. The practical benefit for the modelling community is a much better understanding of how 'soft' driver behaviour factors propagate through the system as a whole, and moreover, how to turn them into an advantage. One line of enquiry which is not expressed in the early and late-merging experiments conducted previously would be to focus attention on the causes of driver behaviour (the social psychological factors) rather than the symptoms (the behaviour itself). Is it possible to influence a driver's attitudes or beliefs and therefore the behavioural outcome? The theory of planned behaviour suggests it is. If so, it could prompt some highly novel user-centred interventions which, in turn, could enable more maintenance to be performed, more quickly, with reduced impacts on the wider network, and with reduced costs. In effect, an applied ergonomics perspective could, in a very real sense, help to regain the lost lane of capacity resulting from real-

world driver behaviour interacting with an ostensibly engineered environment. Engaging with the transport modelling community on this topic suggests they are in a mood to question traditional approaches to problems like roadworks and attempt something new.

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